Where are things shaking? A seismological perspective for potential landing sites on Europa

M. P. Panning[1], S. Tharimena[1], B. Schmidt[2], S. C. Stähler[3], S. D. Vance[1], T.A. Hurford[4], N. Schmerr[5], and S. Kedar[1]

1. Jet Propulsion Laboratory, California Institute of Technology, 2. Georgia Institute of Technology, 3. ETH Zürich, 4. NASA Goddard Space Flight Center, 5. University of Maryland

Jet Propulsion Laboratory
California Institute of Technology

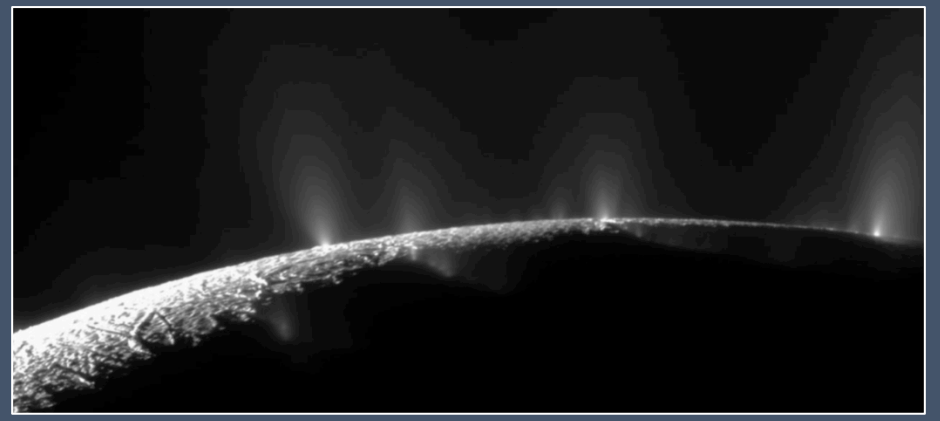
Seismology on Europa and other ocean worlds

Sources

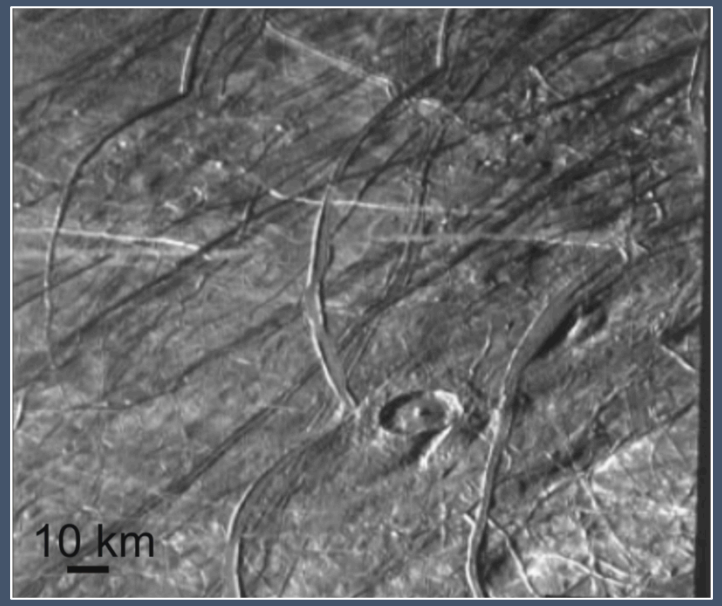
- Fracture
- Tides
- Fluid flow
- Cryovolcanoes
- (Impacts)

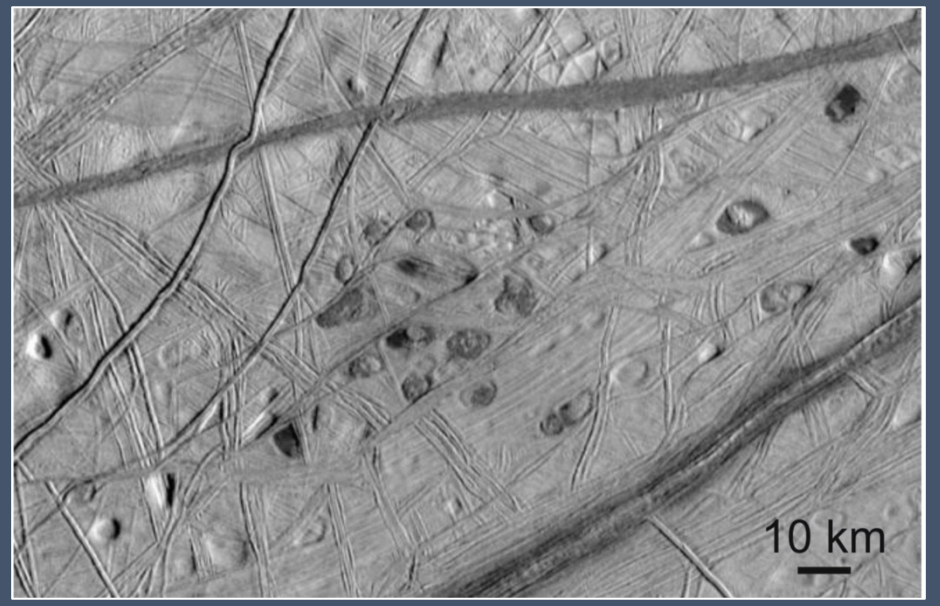
Structure

- Ice shell thickness
- Ocean depth
- High pressure ices
- Rocky interior
- Near-surface material

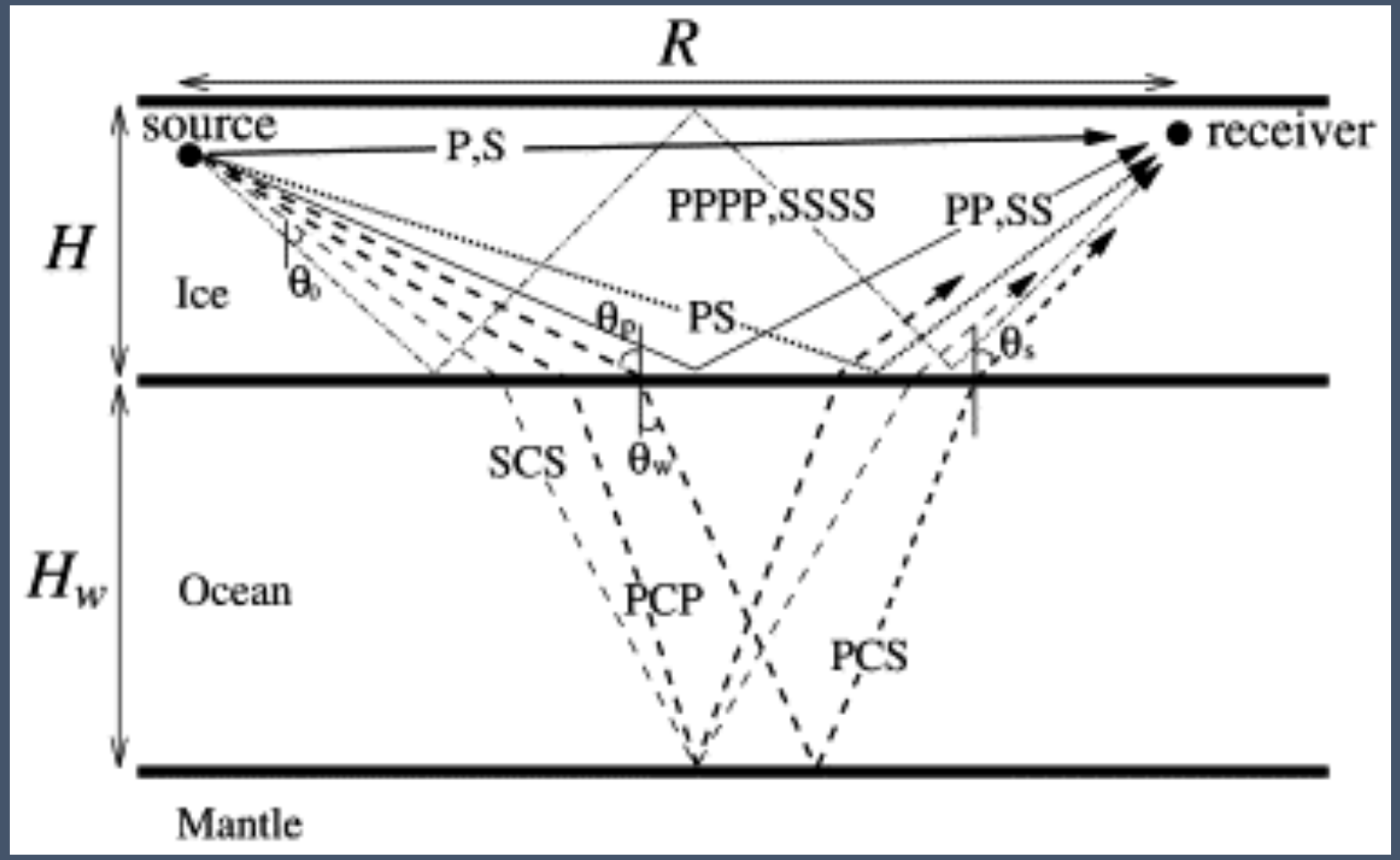


Yes, I know this is Enceladus, but we may have plumes on Europa, too!





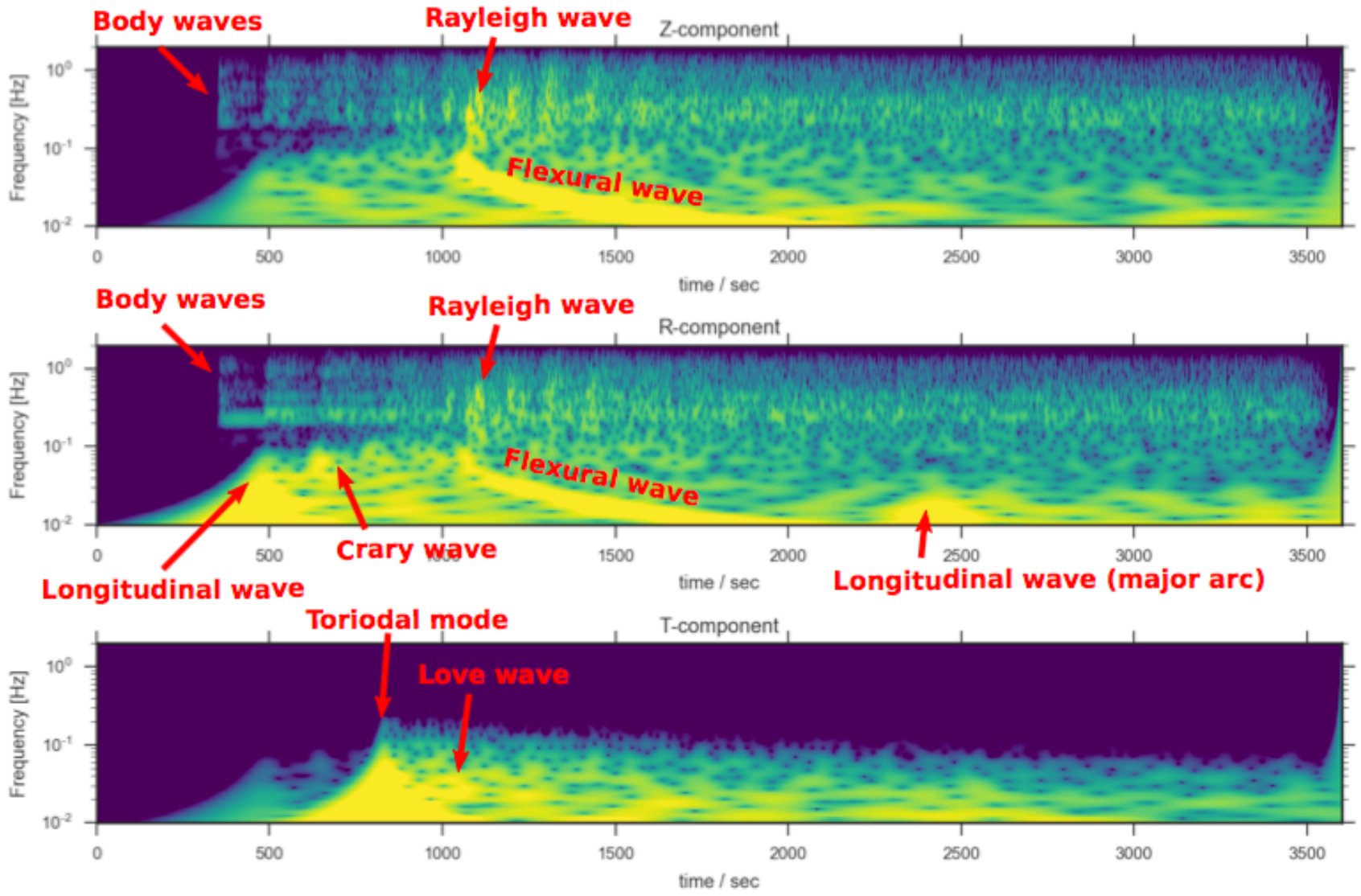
Icy ocean world seismology



From Lee et al., 2003

The most obvious target for seismology is to determine ice shell thickness and ocean depth via timing of reflected waves which can be recorded at relatively high frequencies (e.g. 1-10 Hz)

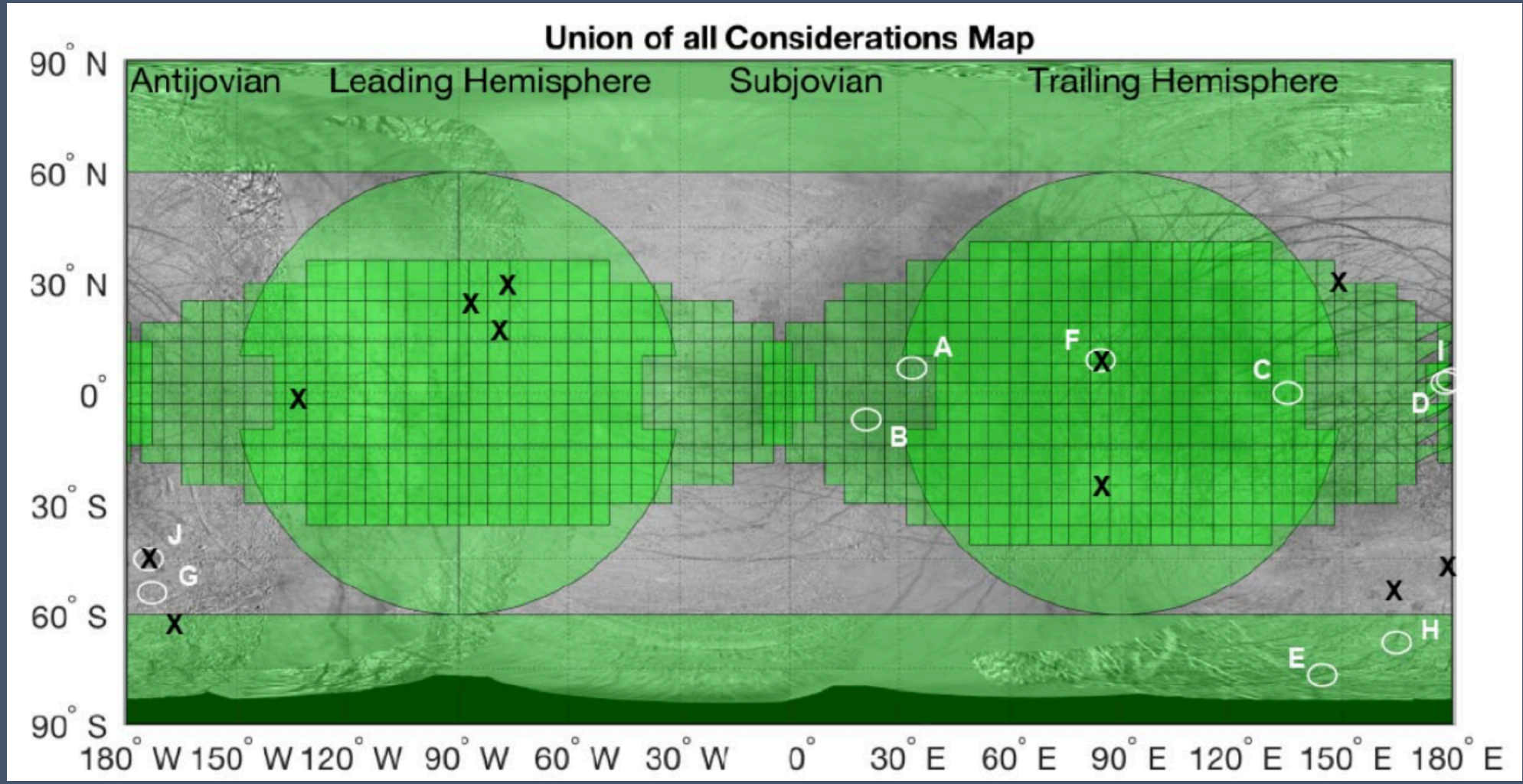
Ice phases



From Stähler et al., 2018

Many other signals are present in the broadband signal that can be used to determine ice shell thickness and other properties, such as flexural waves and resonant Crary waves.

Where not to land (according to Europa Lander Science Definition Team, Hand et al. 2016)



Don’t land on the green if you don’t want too deep of irradiation and you want to land safely using Terrain Relative Navigation and high resolution imagery from EIS Narrow Angle Camera on Europa Clipper

How about landing near places that are seismically active?

- Model likely icequake distribution based on tidal dissipation
- Look for sites that are geologically ”youngest”

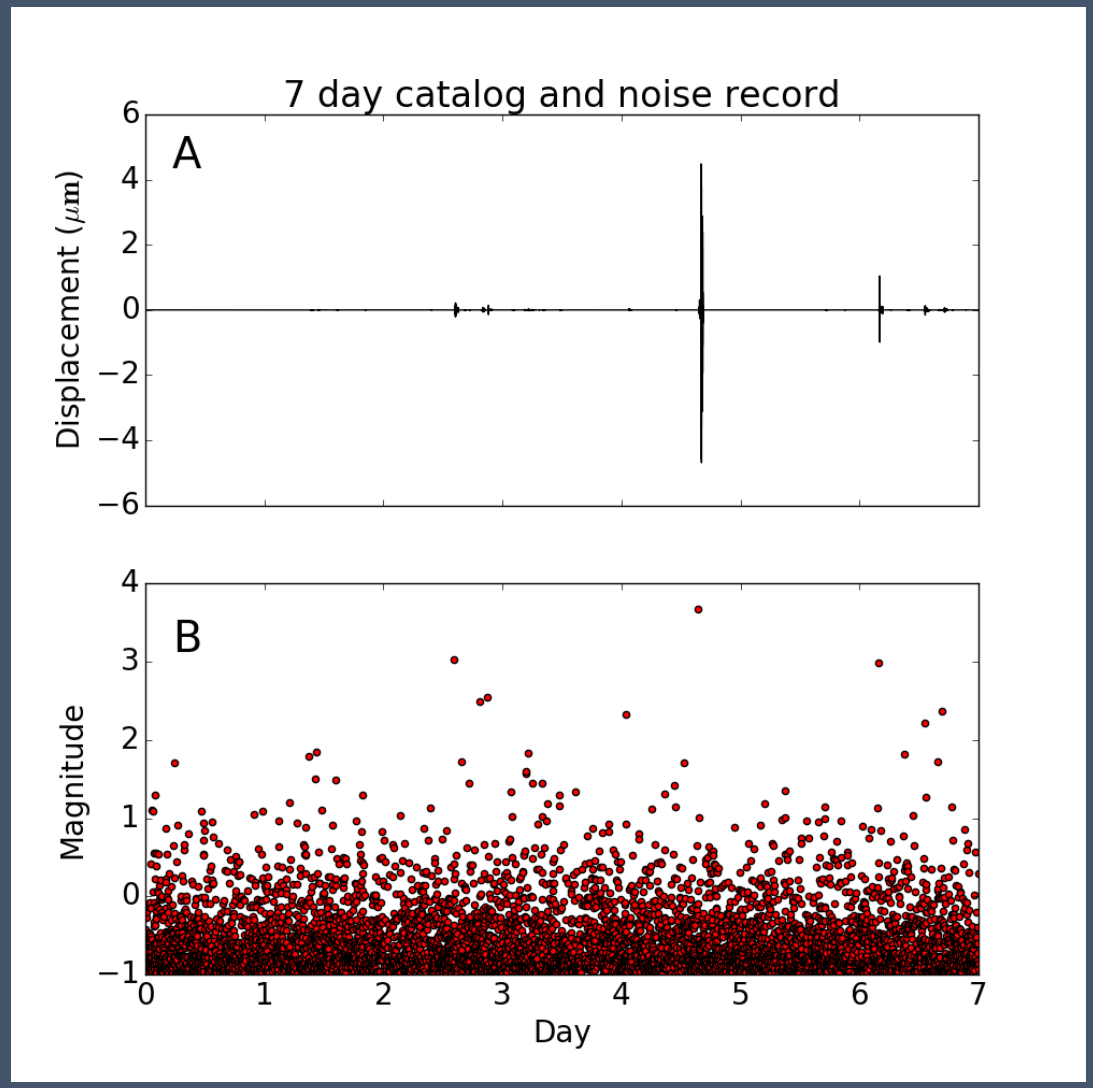
Building an icequake seismicity model

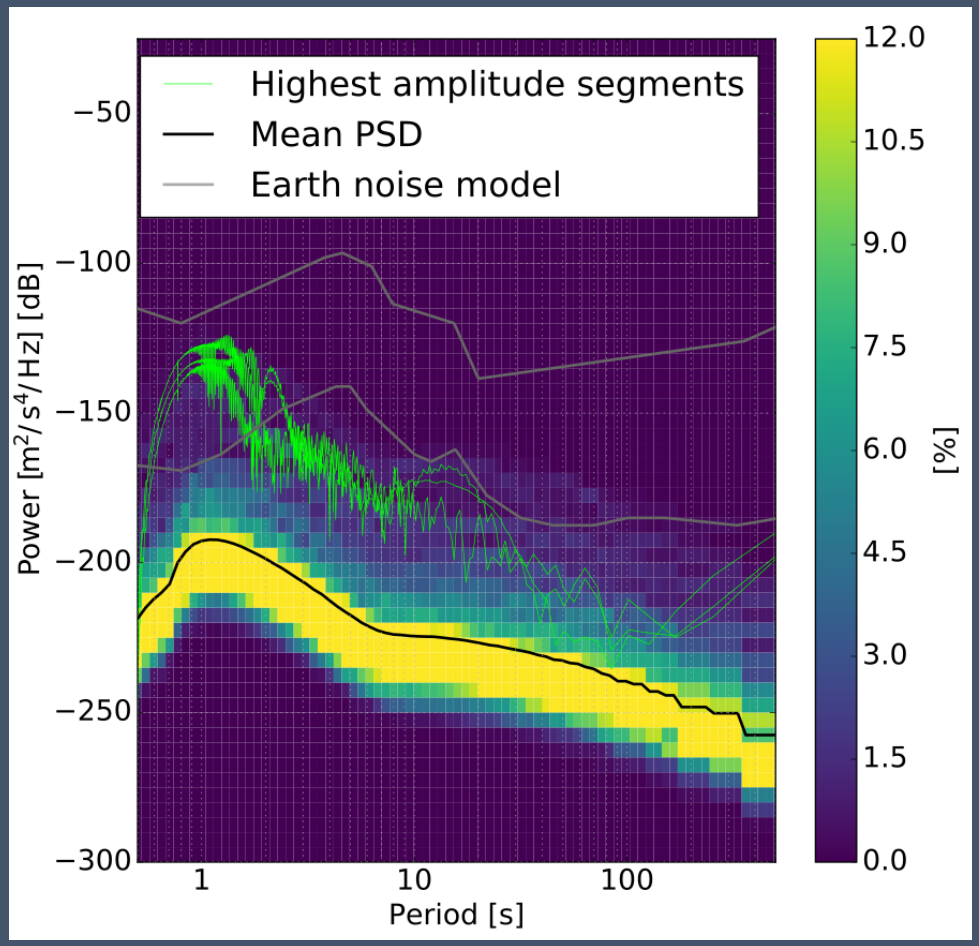
- Assume icequakes follow a Gutenberg-Richter relationship, $\log_{10} N(M_W) = a - bM_W$, so we can define expected seismicity through *a* and *b*
- We can tie this to energy constraints, by rewriting in terms of seismic moment as $N(M_0) = AM_0^{-B}$
- With some manipulation, we can relate this to cumulative seismic moment and maximum event size as $\Sigma M_0 = \frac{AB}{1-B}(M_0^\star)^{1-B}$

Cumulative seismic moment

Maximum event size

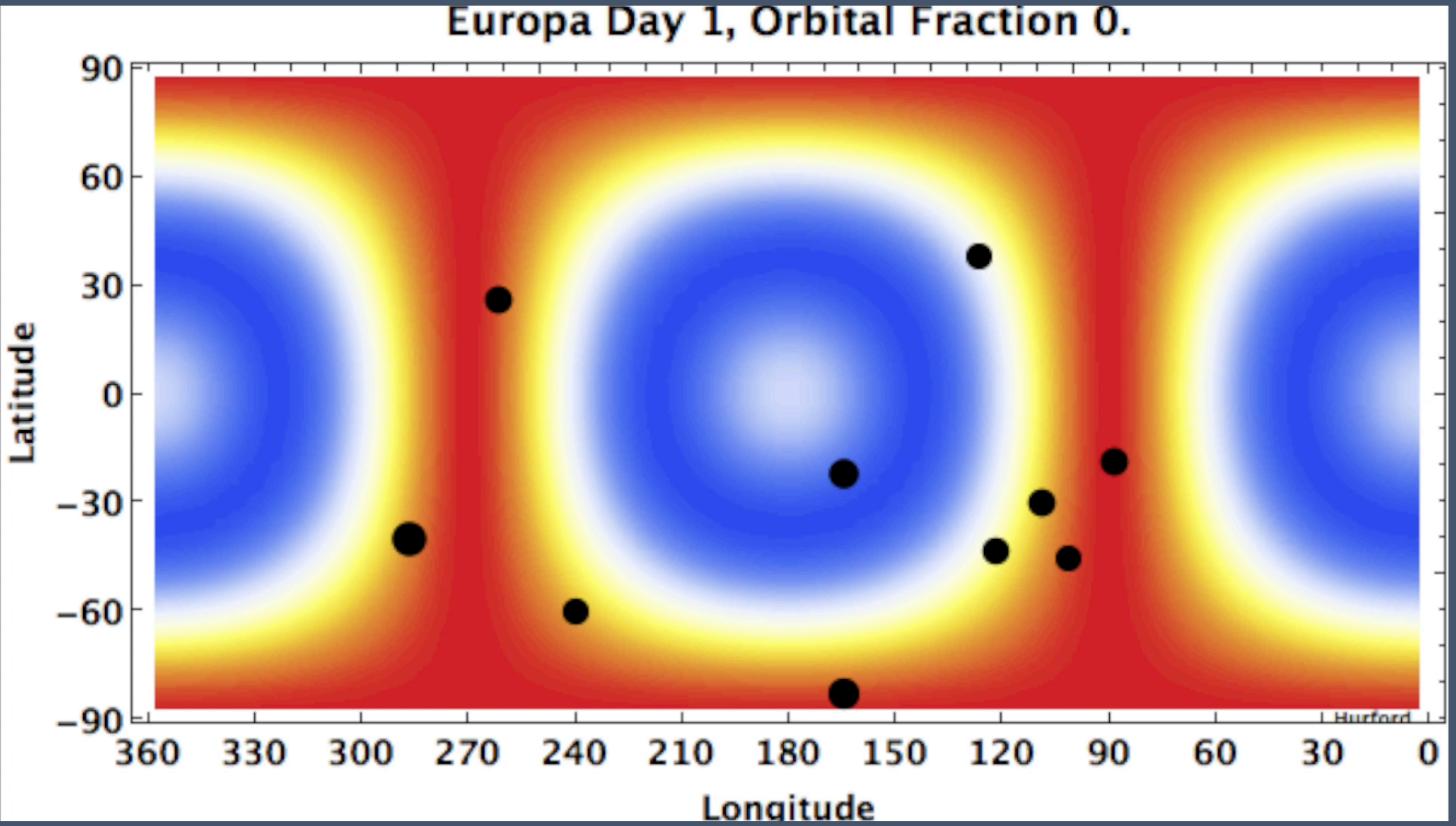
Simulated Europa icequake catalogs and noise





Icequake catalog and synthetic seismic record (left) and estimated acceleration power spectral density for best guess model of Europa seismicity

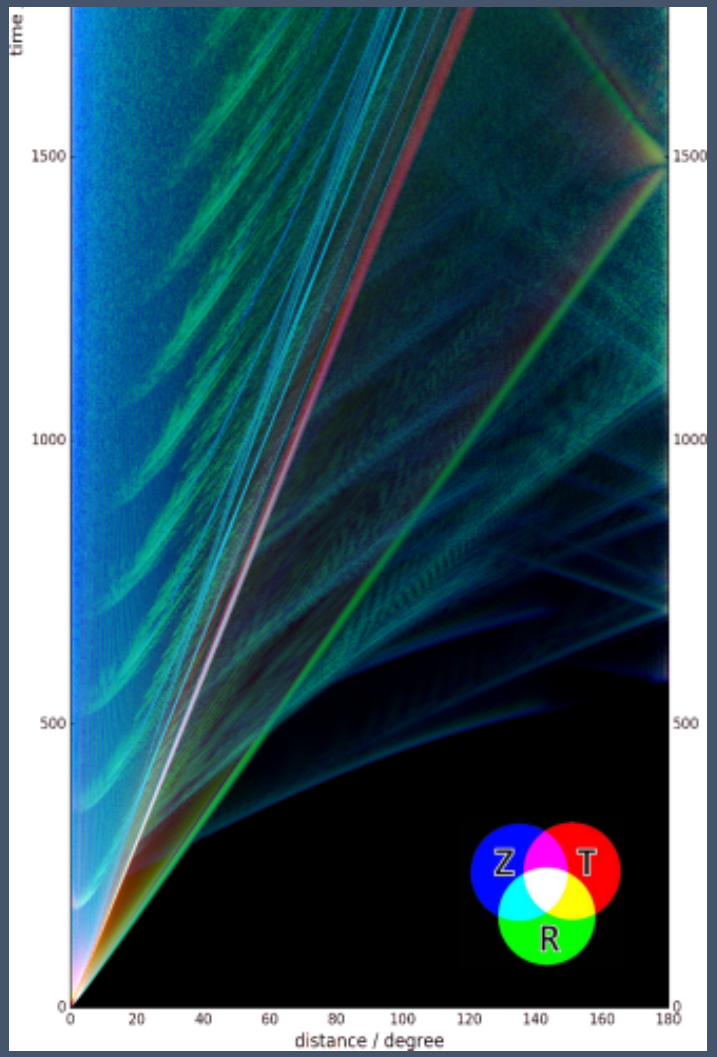
Adding in spatiotemporal variability



- Assume event probability scales with spatial and temporal variation of tidal dissipation energy
- Use this to generate lots of random event sequences
- The following figures are derived from random catalogs generated over 2500 random tidal cycles

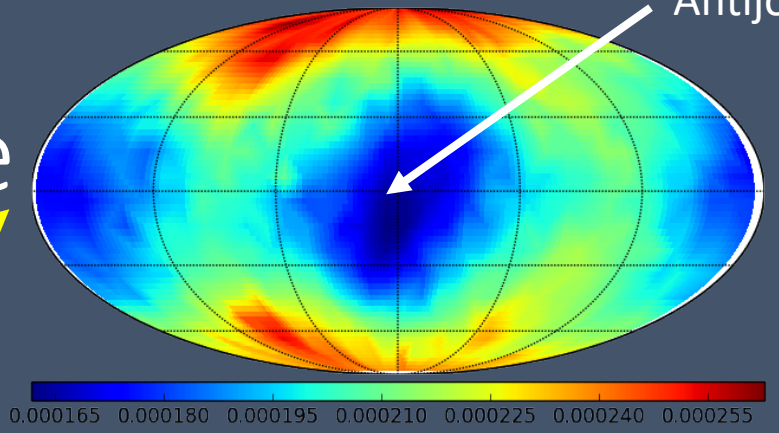
From Hurford et al., 2018 LPSC and submitted to Icarus, arXiv:1811.06536

Expected peak ground acceleration in each cycle

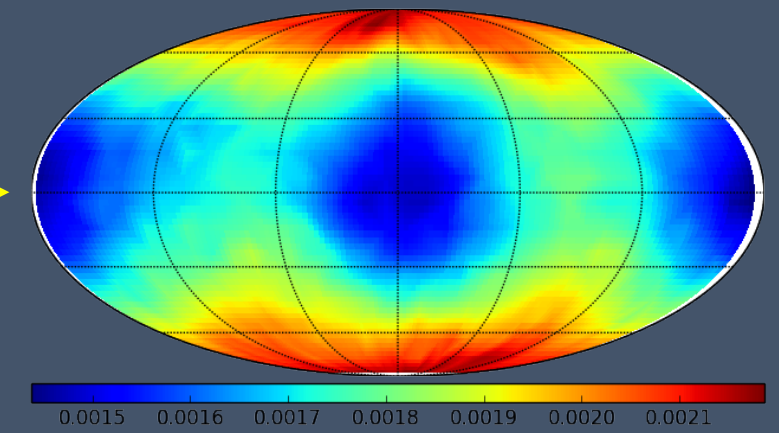


Adapted from Stähler et al., 2018

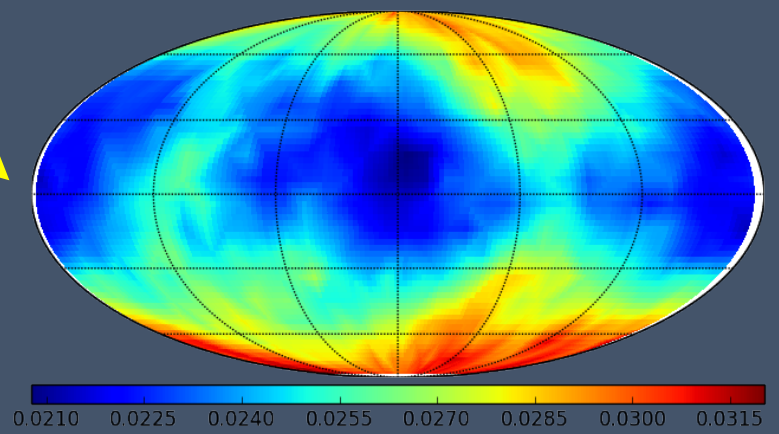
Signals to the right simulated with 20 km thick ice shell. 5 km thick ice shell is a little lower amplitude



5th percentile
PGA: ~2e-4 m/s²

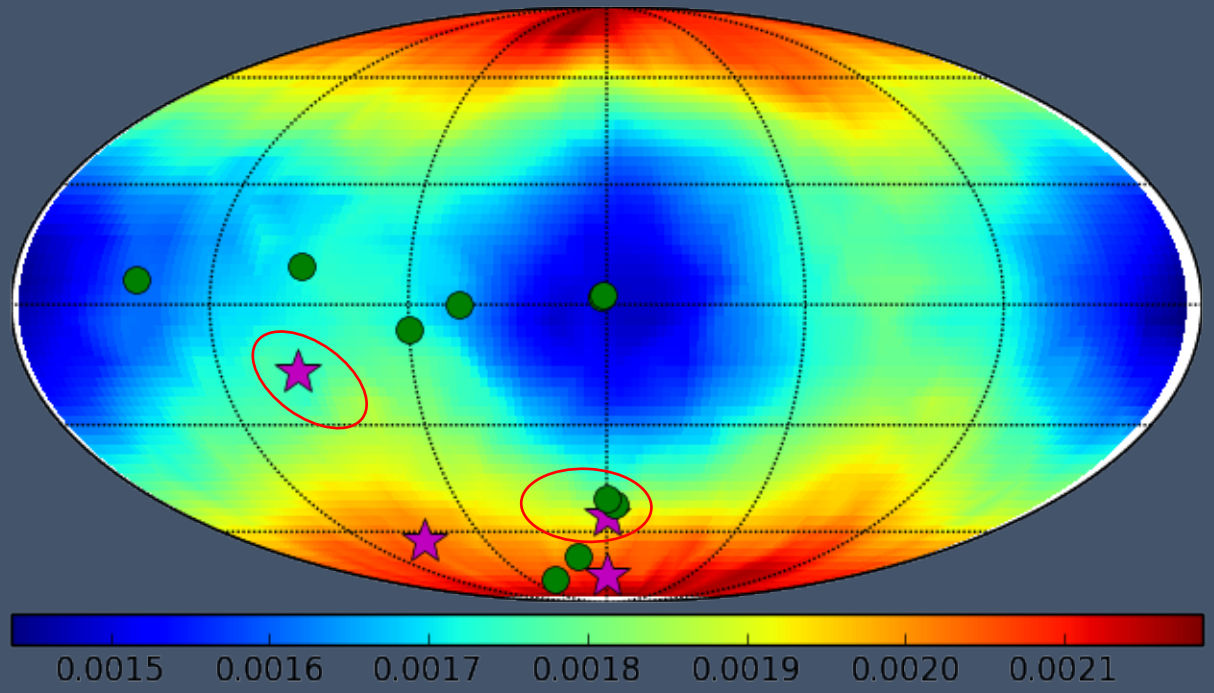


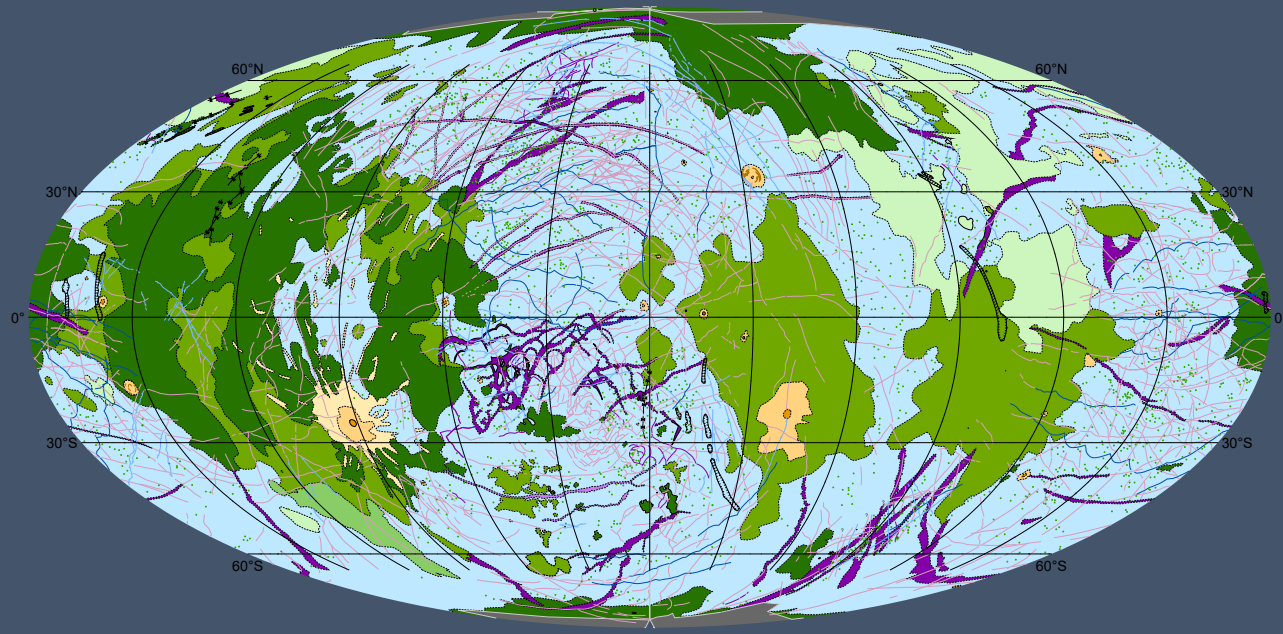
Median expected
PGA: ~2e-3 m/s²



95th percentile
PGA: ~3e-2 m/s²

Zoom in and compare with geology

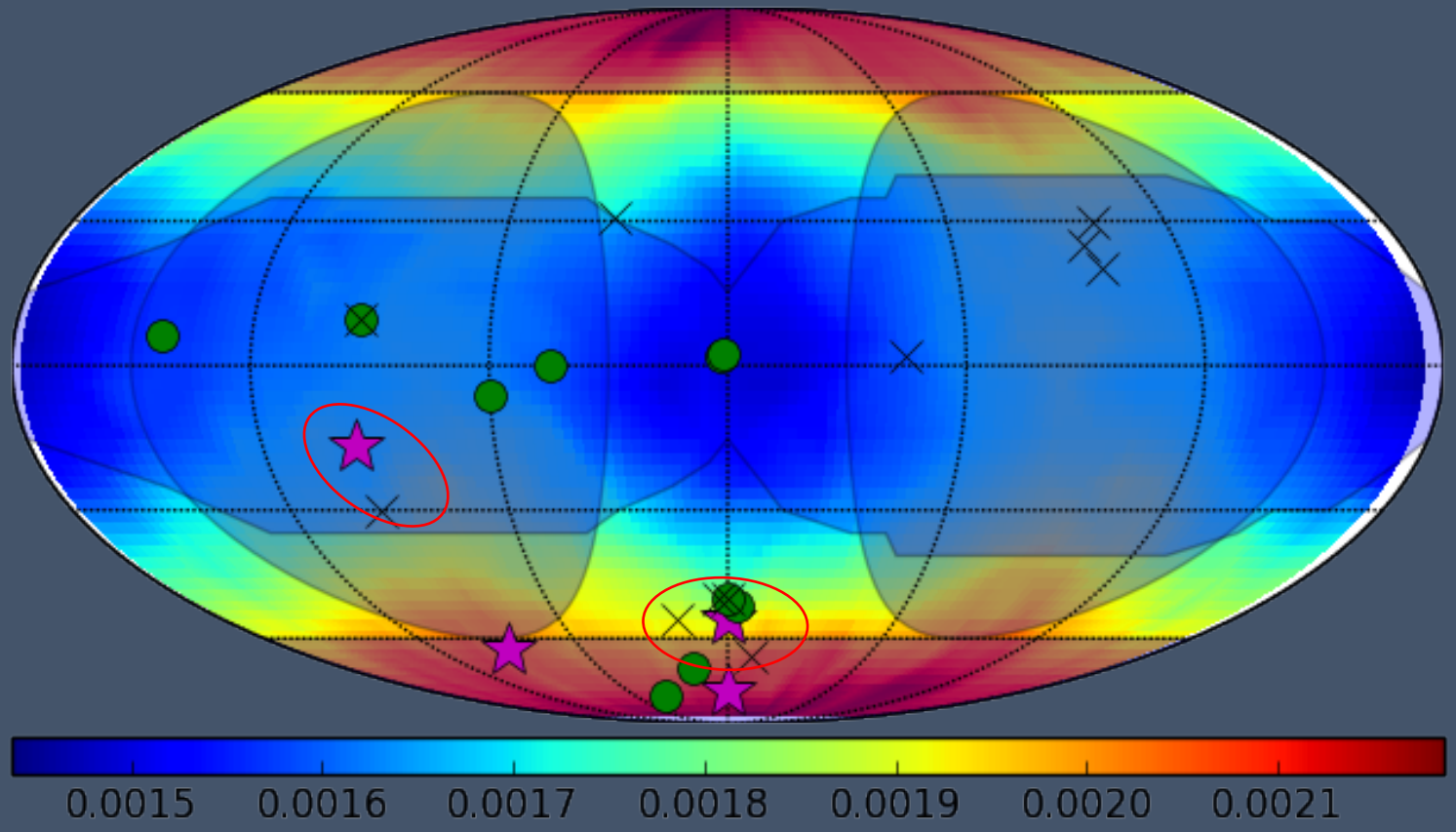




Stars are possible plume observations
Green dots are geological sites of interest identified in SDT report

Geologic map from Leonard et al., 2018 (in revision) and Senske et al., 2018 (LPSC). Green areas are youngest by cross-cutting

Compare with SDT

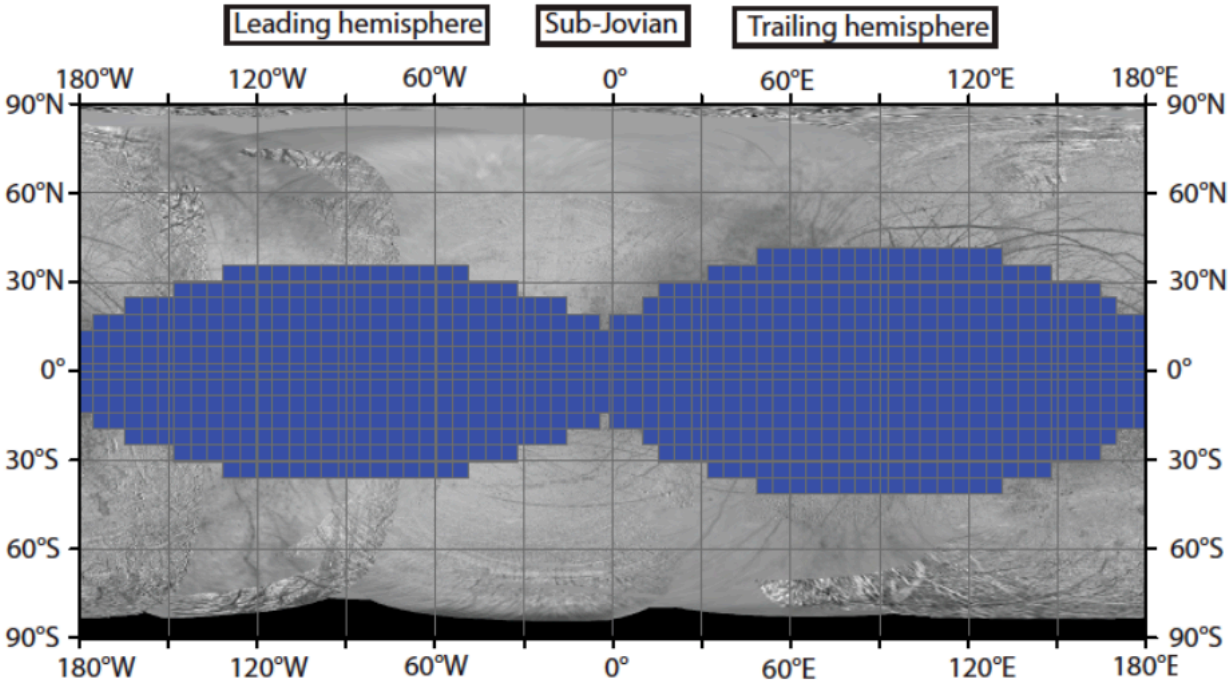


- Southern point is near Thera Macula (Schmidt et al., 2011), as well as possible pull-apart basin (Ivanov et al., 2011), and potential plume observation (Roth et al., 2014), and meets all SDT exclusions
- Trailing hemisphere is near only repeated possible plume observation (Sparks et al., 2017) and geologically “younger” area, but violates landing safety and radiation concerns

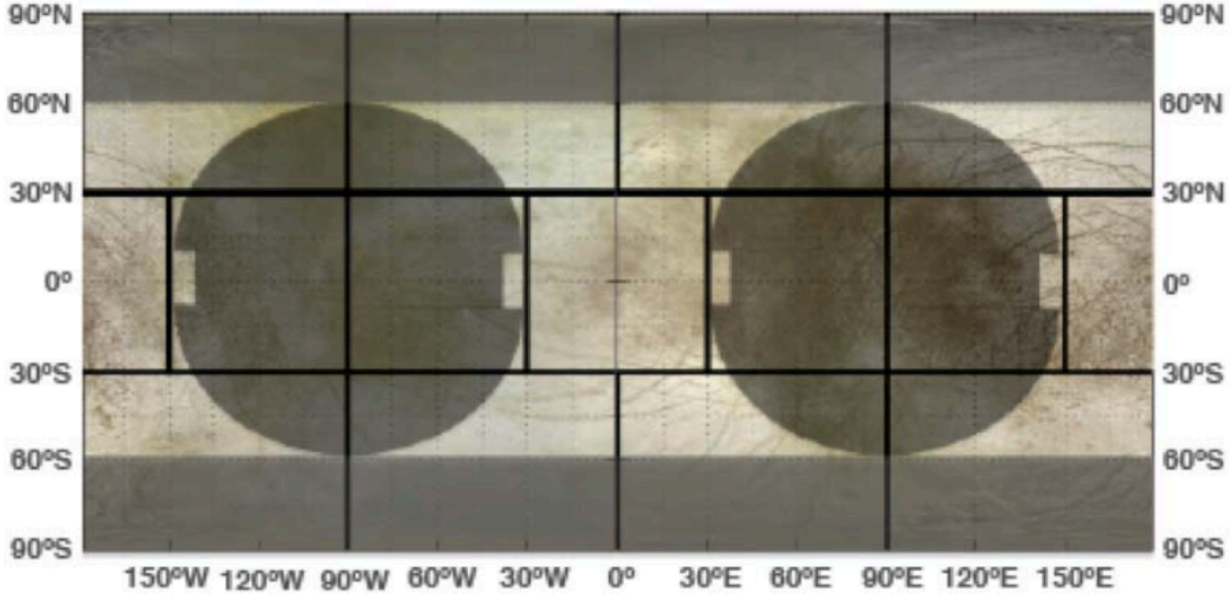
Conclusions

- Seismology on Europa is a really good tool for determining subsurface structure complementing radar observations
- Scaling seismicity by tidal dissipation energy suggests observable seismic signals in every tidal cycle
- Spatiotemporal variation of tidal dissipation suggests higher seismicity at high latitudes and away from sub- and antijovian points
- Given SDT-defined landing safety and radiation constraints, landing near Thera Macula represents good seismic and geologic potential
- If another mission can consider trailing hemisphere sites, landing near Pwyll and the Sparks et al. plume also should have reasonable seismicity

Where not to land (according to Europa Lander Science Definition Team, Hand et al. 2016)

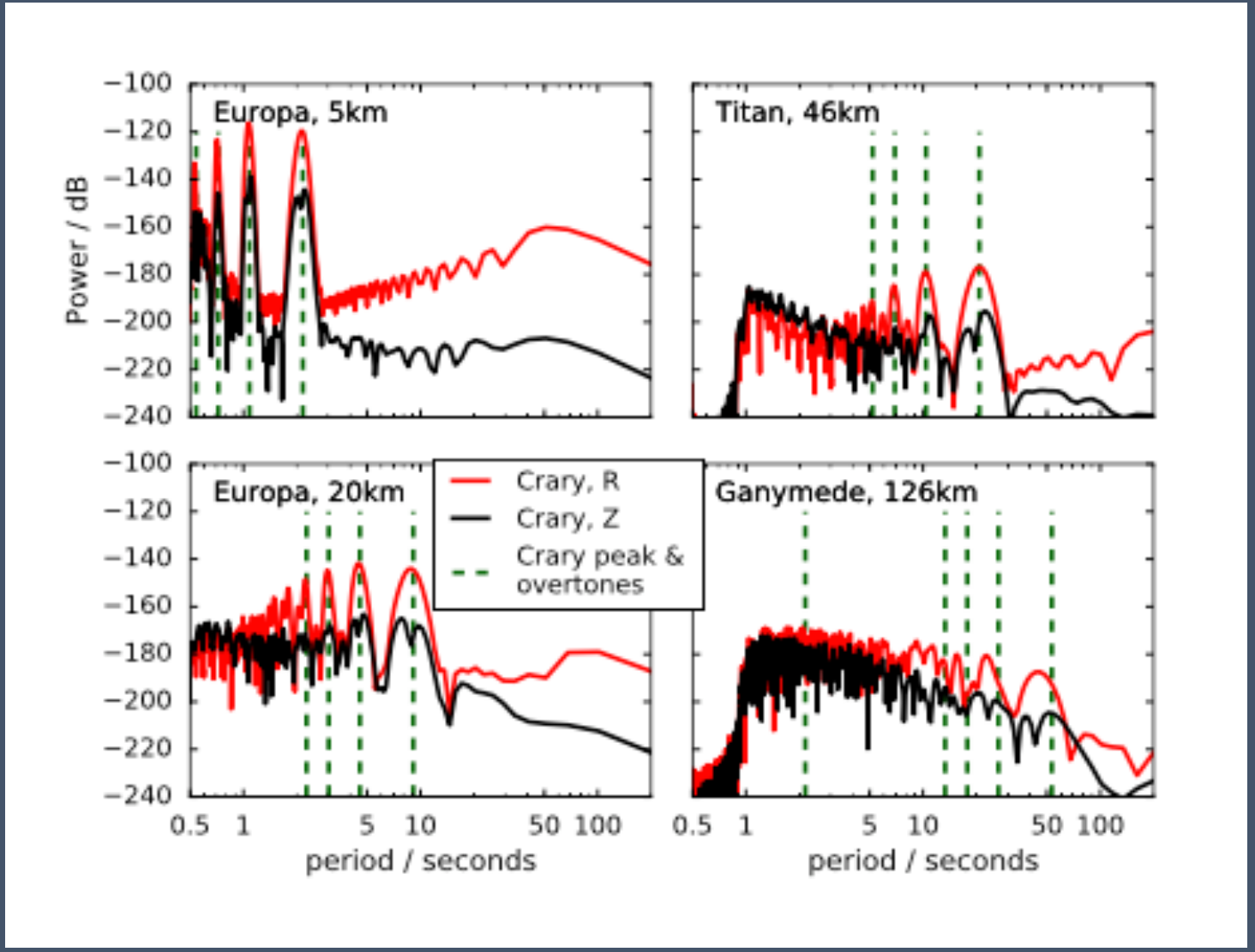


Significant radiation to depths >10 cm (based on Nordheim et al., 2017)



Excluded sites based on landing safety due to shadows and possible lack of high res images from Europa Clipper

Crary wave resonance peaks



From Stähler et al., 2018